Ohms Per Square What!

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Is it ohms per square meter or ohms per square inch? Which is it? Actually, it is none of these, but **"ohms per square anything."** However, this confusing term that has been used to describe the **Surface Resistivity** (ρ) of a material. Is it here to stay forever? The ESD Association Glossary, ESD-ADV 1.0-1994 (1), describes **Surface Resistivity** in the following way: "For an electric current flowing across a surface, the ratio of DC voltage drop per unit length to the surface current per width. In effect, the surface resistivity is the resistance between two opposite sides of a square and is independent of the size of the square or its dimensional units. Surface resistivity is expressed in ohms per square. When using a concentric ring fixture, resistivity is calculated by using the following expression, where D1 = outside diameter on an inner electrode, D2 = inside diameter of the outer electrode and R = measured resistance in ohms: (from EOS/ESD-S11.11 - 1993)(2)."

Surface Resistivity $(\rho_s) = \{2\pi /[\ln(D1/D2)]\}R$

Some have asked, why use this allegedly ambiguous term and measurement? Can't we just use ohms? Because of the geometry of the EOS/ESD-S11.1 concentric ring electrode, the resistance is simply ρ_s**/10 ohms**. One could further argue, why not just always use this resistance in **ohms** result?

In order to answer these questions, we need to examine the history of **ohms per square**. For a number of years the **surface resistivity** was a pure number with no dimensions. Valdes (3) in 1954, wrote about the four-point probe method to make resistivity measurements on germanium transistors. However, all this work, and later work by Uhlir, (1955)(4), assumed a three-dimensional structures with one infinite dimension. Their work was expanded by Smits (5) in 1958 for two-dimensional structures. Smits defined a four-point probe method of measuring **"sheet resistivities."** This work eventually became an industry standard for measuring the resistivity of diffused layers in semiconductors. He developed correction factors for measuring sheet resistivities on two-dimensional and circular samples using a four-point probe where the two outer probes source current and the two inner probes measure voltage. He found that this method was not only useful for measuring diffused surface layers, but was useful in obtaining **"body resistivities"** of thin samples. Yet in all this work **sheet resistivity** (ρ_s) had no dimensions, but was a pure number. Although

Smits showed that body resistivity (ρ) was equal to sheet resistivity (ρ_s) times w, where w is the thin sample thickness, he did not assign the dimensions, **ohm-cm**, to this resistivity. The term he called "body resistivity," we now commonly call "volume resistivity" or "bulk resistivity." It is interesting to note that in Smit's work that he never uses the term "sheet resistance." He developed the relationship that:

Sheet Resistivity $(\rho_s) = V / I (\pi /\ln 2) = V / I (4.5324)$

In 1962, Irvin (6) developed curves showing the **resistivity** in **ohm-cm**, versus Impurity concentration of various doping levels in silicon. Here he defined the **"bulk resistivity"** as **ohm-cm**. The resistivity is again dimensioned as **ohm-cm**. There is no mention in this publication of sheet resistance or ohms per square.

In 1968 in a book by Berry, etal. (7), the authors state that the resistance of a thin-film resistor is directly proportional to the resistivity, ρ , and inversely proportional to the thickness, **d**. They introduce the term **"sheet resistance (Rs)"** to define thin film resistor parameters. They define it as:

$$Rs = \rho / d$$

The authors further explain that the **sheet resistance** may be thought of as a material property since the film is essentially two-dimensional. Therefore, a simple thin film resistor consisting of a simple rectangle of length **l** (in the direction of the current) and the width **w** has a resistance of:

$$R = (\rho / d) \, (l/w) \text{ or}$$

$$R = Rs \, (l/w)$$

The authors claim that the term **(l/w)** is sometimes called the number of squares in the resistor, since it is equal to the number of squares of side **w** that can be superimposed on the resistor without overlapping. They assert that the term "squares" is a pure number, having no dimensions. The author's state that the sheet resistance has the unit of ohms, but it is convenient to refer to it as **"ohms per square"** since the sheet resistance produces the resistance of the resistor when multiplied by the number of squares. They go on to say that the concept can be broadened to include any arbitrarily shaped resistor by calling the quantity **Rd/ρ** the effective number of squares. The authors expand on the use Smit's four-point probe technique and introduce new correction factors for the size of their substrate. It turns out that the four-point probe is a useful tool to check the uniformity of thin-film resistors.

The term **"sheet resistance"** has not only shown up in defining materials to control ESD. It is also used to define resistive seas and overcoats of all types including the coatings on cathode ray tube (CRT) monitors to reduce the second anode electric fields that could be coupled to a person touching the screen. It is also used to describe the resistance of the semitransparent layer that composes one terminal of a liquid crystal display (LCD). The term continues to be used to define the resistance of both thick and thin-film resistors. In a notable book on the physics of semiconductors by Sze (8) in 1981, the term **sheet resistance** is not found to describe the characteristics of semiconductors. Only the term **resistivity** is used.

So now you know where the dimension **"ohms per square"** apparently originated. It appears that we are stuck with this term unless the authors of the ESD Association Glossary decide to redefine it and use only the dimensions **ohms** and **ohm-cm** for surface and body (volume or bulk) resistivity respectively.

Therefore, it would seem reasonable that **surface resistivity** should always be measured in **ohms** and **volume resistivity** in **ohm-cm,** as Jonassen (9) has argued for a number of years.

Maybe we should leave the term **sheet resistance** and **ohms per square** to the thick and thin film

resistors and hybrid integrated circuit people, where it makes some sense to them and stick to using **ohms**.

References

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